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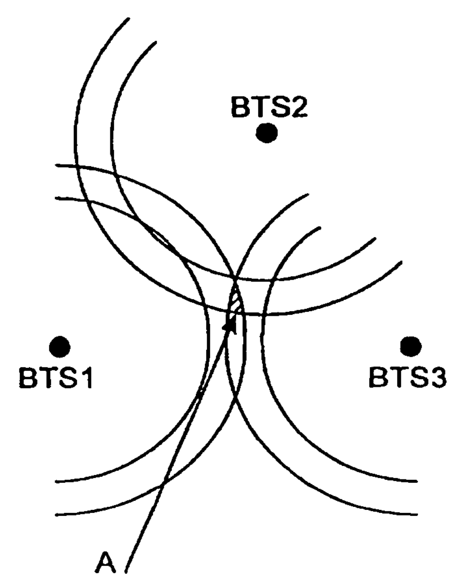
(57) Abstract

The invention relates to a method for locating a mobile station in a digital time division mobile communication system. The serving base station (BTS1) determines the timing of the transmission of a mobile station by means of a timing advance so that the transmission of the mobile station is received at the serving base station (BTS1) in a correct time slot. Correspondingly, timing advances suitable for timing the transmission of the mobile station (MS) are measured at neighbouring base stations (BTS2, BTS3), and the timing advances are converted into base station distances. An inaccuracy term is added to the base station distances, and the location of the mobile station is determined to be the intersection (A) of the base station distances rectified with the inaccuracy term.



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Locating a mobile station in a digital mobile communication system

Field of the Invention

The invention relates to a method for locating a mobile station in a digital time division mobile communication system where the serving base station determines the timing of the transmission of a mobile station by means of a timing advance so that the transmission of the mobile station is received at the serving base station in a correct time slot. The timing advance data are converted into base station distances. In the mobile communication system, the mobile station measures signals from neighbouring base stations and reports the measurement results to a base station controller.

Background of the Invention

It is sometimes important to know the location of a mobile station as accurately as possible. In the case of an emergency call, for example, the caller is not always able to define his location accurately. In such a case, knowledge of the accurate location of the mobile station may essentially expedite the arrival of the help needed. Mobile communication systems need the location data of a mobile station for routing calls and for other services. The location of each mobile station is usually stored in the network registers with an accuracy of a location area. The network operator may determine the size of a location area. However, if the location area is very small, the location updating of a mobile station causes excessive load in the network. Location area information is therefore not sufficiently accurate for determining the exact location of a mobile station.

The prior art teaches locating a mobile station

by a distance determination method based on radio path attenuation. WO 9507587 discloses a method in which a mobile station measures the signal strengths of neighbouring base stations. The distance of the mobile station from each base station is determined on the basis of the signal strengths. A theoretical geographical distance between transmission and reception is calculated on the basis of radio path attenuation, which is defined as the remainder of the transmitted and received signal strength. Nevertheless, determining the distance on the basis of radio path attenuation is not a very reliable method on account of the varying conditions on the radio path employed, for instance occasional attenuating obstacles such as large vehicles and changes in weather conditions. Another factor that makes the method unreliable and complicated is the variation of the radiation power of base stations, for example because the transmission power has been adjusted or ice has accumulated on the antennas.

Figure 1 of the accompanying drawings shows a simplified block diagram of the pan-European GSM mobile communication system. A mobile station MS is connected over a radio path to a base transceiver station BTS, BTS1 in the case of Figure 1. When the BTS1 rejects the access attempt of the mobile station, the mobile station will attempt to access the base station with the next highest signal level, e.g. BTS2. A base station system BSS consists of a base station controller BSC and base transceiver stations BTS under its control. A plurality of base station controllers BSC usually operate under a mobile services switching centre MSC. An MSC is connected to other MSCs and, via a gateway mobile services switching centre GMSC, to a public switched telephone network. The operation of the entire system is controlled by an operation and maintenance centre

OMC. The subscriber data of an MS are permanently stored in a home location register HLR of the system and temporarily in the visitor location register VLR in whose area the MS is currently located. The VLR stores the location data of an MS with an accuracy of a location area LA. The geographical area monitored by a VLR is divided into one or more location areas LA. One or more base stations BTS may operate in each location area. An MS continuously measures the signals from the base stations BTS that are closest to its location for a possible crossover. In a GSM mobile communication network, for example, the MS may simultaneously measure the signal level and/or quality of both the serving base station and up to six other base stations. The serving base station informs the mobile station of the neighbouring base stations it should measure. Each base station BTS is identified on the basis of a base station identity code. The mobile station MS sends the measuring results regularly as a report message through the serving base station BTS to the base station controller BSC.

In digital time division multiple access (TDMA) radio systems, a plurality of mobile stations MS may use the same carrier frequency, i.e. radio channel, on a time division basis for communication with the base station BTS. A carrier is divided into successive frames that are further divided into time slots, e.g. eight time slots, allocated to the users according to the need. Short data bursts are sent in the time slots. The MS is synchronized with a signal received from the BTS and transmits a burst in accordance with this sync so that the burst from the MS is received at the BTS in a time slot allocated to this particular MS. The mobile stations are located at different distances from the BTS. The propagation delay caused by the distance must

be taken into account in such a manner that the signal is received at the base station in a correct time slot. For this purpose, the base station BTS measures the time difference between its own transmission and the transmission received from the MS, and on the basis of this difference determines a suitable timing advance for the MS to compensate for the propagation delay. By means of the timing advance, the MS advances its time of transmission relative to a basic time instant defined by the sync received from the base station.

The GSM recommendations disclose determining the distance of an MS on the basis of timing advance in the second system generation. From the timing advance, which compensates for the propagation delay of a radio signal, it is possible to calculate the distance travelled by a radio signal propagating at the velocity of light. The distance travelled gives the distance between the serving base station BTS and the MS, when it is taken into account that the radio signal has travelled once back and forth between the BTS and the MS. The resolution of the duration of one bit in the timing advance causes a resolution of about 550 metres in the distance data. Synchronization errors and multipath propagation are factors that further increase the inaccuracy of the distance data. The location of an MS can thus be confined in a known manner to a calculated distance from the base station with a certain margin. Since it is not known in which direction from the BTS the MS is located, the location of the MS can only be determined to be within an area between two circles centred round a base station but having a different radius. In practice, this makes the locating of an MS very inaccurate.

Brief Description of the Invention

The object of the present invention is to locate an MS as accurately and unambiguously as possible.

This new type of determining the location of a calling mobile station is achieved with a method of the invention, which is characterized in that it comprises measuring, at one or more neighbouring base stations, timing advances suitable for timing the transmission of the mobile station, adding an inaccuracy term to said base station distances, and determining the location of the mobile station as the intersection of the base station distances rectified with the inaccuracy term.

The invention is based on the idea of defining the distance of a mobile station from a plurality of base stations by means of a timing advance, whereby the mobile station is located in the intersection of said distances.

Advantages of the Invention

An advantage of such a method for locating a mobile station is that, in the event of an emergency, help can be provided more rapidly and reliably to the correct place.

A further advantage of the method of the invention is that the results are not affected by weather conditions or changes in the radiation power of a base station.

Brief Description of the Drawings

In the following, the invention will be described in greater detail with reference to the accompanying drawings, in which

Figure 1 shows parts of a mobile communication

system that are relevant to the invention,

Figure 2 shows a flow diagram of a preferred embodiment of the method of the invention,

Figure 3 shows an exemplary graphical printout in the case of two base stations,

Figure 4 shows an exemplary graphical printout in the case of three base stations, and

Figure 5 shows an exemplary graphical printout in the case of three advantageously positioned base stations.

Detailed Description of the Invention

The present invention is intended to be applied in any radio network based on digital time division multiple access (TDMA) and employing a timing advance for shifting the time of transmission of a mobile station in relation to a time instant set by a sync signal transmitted by the base station in such a way that the timing advance compensates for the propagation delay caused by the distance between the base station and the mobile station, and that the transmission of the mobile station is received at the base station in a correct TDMA time slot. The invention is particularly suitable for use in the GSM and DCS1800 mobile communication systems. For a more accurate description of the GSM system, reference is made to the GSM recommendations and "The GSM System for Mobile Communications" by M. Mouly and M-B. Pautet, Palaiseau, France, 1992, ISBN: 2-9507190-0-7. In the following, the invention will be described in greater detail with reference, by way of example, to the GSM mobile communication system.

Figure 1 illustrates the above-described network elements of a mobile communication system that are relevant to the invention.

Figure 2 is a flow diagram illustrating a primary embodiment of the method of the invention. The method partly utilizes the normal functions of a mobile communication system in a new combination so as to provide the functionality according to the invention.

According to the preferred embodiment, the functionality of the method of the invention is activated when a call is identified as an emergency call (step 21). The identification is performed, for example, by comparing the directory number of the called party with predetermined emergency numbers. In the GSM system, emergency calls have a separate cause code, on the basis of which an emergency call can also be identified. The functionality of step 21 can also be implemented by manual control by a network supervisor, for example, when the network supervisor is informed by an emergency service centre about the need to start a location process. All other calls to the mobile station are prevented during the location.

According to the prior art, the serving base station BTS1 - normally at the beginning of a call and if necessary also during the call - measures the time difference between its own transmission and the transmission received from the mobile station MS. On the basis of this time difference, the BTS1 determines a suitable timing advance TA_1 for the MS to compensate for the propagation delay. By means of the timing advance TA_1, the MS advances its time of transmission relative to the basic instant defined by the sync received from the base station.

The method of the invention comprises measuring - from as many neighbouring base stations as possible, one at a time - a timing advance TA_1 suitable for each base station connection (step 22 in Figure 2). The identities of up to six best neighbouring base

stations last reported by the MS are stored in the base station controller BSC or the mobile services switching centre MSC, for example, and the timing advance measurements are made at these neighbouring base stations, e.g. BTS2 and BTS3 in Figure 1. If necessary, the measurements can also be made at other neighbouring base stations.

According to the preferred embodiment of the invention, the timing advance measurement at the neighbouring base stations is carried out by short-term temporary handovers from the serving base station BTS1 to a measuring neighbouring base station, e.g. BTS2, in the case of an emergency call without releasing the call. A handover between a base station and neighbouring base stations under the same base station controller BSC is controlled by the BSC. If the group of neighbouring base stations participating in the measurement includes base stations under another base station controller BSC (such as BTS 4 to BTS6 in Figure 1), the measuring process is synchronized and the results are compiled in a higher network element, e.g. a mobile services switching centre MSC or an operation and maintenance centre OMC. In the synchronization and management of the measuring process it is essential to ensure that different base stations BTS do not try to measure simultaneously.

For the short-term handover, an MS is commanded to switch from the serving base station BTS1 to an assigned neighbouring base station, e.g. BTS 2. The BTS2 measures the delay in the transmission of the MS either during an access request on a random access channel RACH of the uplink broadcast frequency, or on a traffic channel allocated by the BTS2 to the MS. In other respects, the measurement is made in the same way as at the serving base station BTS1 at the beginning of the

call. If the measurement on the RACH is successful, the actual traffic load of the BTS2 is not increased, since the handover is not completed, i.e. the call remains at the serving base station BTS1, and the neighbouring base station BTS2 rejects the handover attempt after the successful measurement. A timing advance value TA_i is obtained as a result of the measurement for each base station BTSi, where i = 1, 2, 3,... . After the measurement at a neighbouring base station, the call can be returned to the original serving base station BTS1, and from there it may be further handed over to the following neighbouring base station, e.g. BTS3, in the measuring sequence, if any. This handover sequence, e.g. BTS1 - BTS2 - BTS1 - BTS3 - BTS1, is preferably made prior to the beginning of the actual call. To expedite the sequence, it is advantageous in some cases to hand over the call directly from one neighbouring base station to another, e.g. BTS1 - BTS2 - BTS3 - BTS1. The base station controller BSC may employ an expedited sequence particularly when the measurement of the timing advance is made on a traffic channel allocated by each neighbouring station, i.e. the call is handed over from one base station to another.

According to a second embodiment, the timing advance measurement may be made at the neighbouring base stations BTSi after an emergency call has ended by paging the mobile station and by rejecting the access attempt of the mobile station at each base station BTSi. The MS is paged in all the location areas LA having neighbouring base stations participating in the measurement. The paging message is transmitted to the mobile station from all the base stations in the defined location areas. In the case of Figure 1, for example, when the base stations BTS1 to BTS4 participate in the measurement, the MS is paged in all the base stations

BTS1 to BTS6 within location areas LA1 and LA2. The MS tries to respond to the paging by transmitting a burst to the serving base station BTS1 on a RACH at the uplink broadcast frequency. Since the serving base station BTS1, in a normal manner, has already determined a suitable timing advance TA_1 during the call, the base station controller BSC or the mobile services switching centre MSC, for example, commands the BTS1 to reject the access attempt of the MS. According to the functionality defined in GSM Recommendation 05.08, the MS will then attempt access through the base station with the next strongest signal level, e.g. BTS2. The BTS2 measures the propagation delay of the MS and defines a suitable timing advance TA_2. Once the measurement has succeeded, the BTS2 is also commanded to reject the access attempt of the MS, whereby the MS will attempt access to the following base station, e.g. BTS3. The process continues in the same way, and each neighbouring base station BTSi in turn measures a suitable timing advance TA_i and rejects the access attempt of the MS. The functionality will be continued until the timing advances have been measured at each base station BTS1 to BTS4 participating in the measurement, whereafter the paging of the MS will be terminated. The functionality described above does not make the MS alarm the user, since the access attempts made by the MS are rejected, i.e. the call establishment is stopped before the MS alarms.

According to a third embodiment, timing advances can be determined at the neighbouring base stations BTSi when an emergency call has ended by making measurement calls to the MS, i.e. by paging the MS in each or as many BTSi as possible in a sequence. In this embodiment, the MS must be commanded to monitor the control channel of each BTSi in turn, for the MS normally monitors only the control channel of the

serving base station. Each neighbouring base station BTSi in turn measures the propagation delay of the MS when the MS transmits an RACH burst. When a suitable timing advance TA_i has been measured for the transmission of the MS, the establishment of the call is stopped at the BTSi, whereby the MS does not alarm in vain. As a result of the measurement, a timing advance value TA_i is again obtained for each base station BTSi.

The timing advance results TA_i of the neighbouring base stations, obtained as a result of the measurements of step 22 in Figure 1, and the timing advance TA_1 measured by the serving base station for the mobile station are converted in a known manner into distance data $S_i=c*TA_i/2$, where c is the velocity of light (item 23). The distance data S_i together with the base station data are stored in the memory of the base station controller BSC, for example, or some other network element managing the measuring process to wait for further processing. If desired, the distance data S_i can be supplemented with an inaccuracy term ΔS, which is caused particularly by the resolution of the timing advance.

The distance data obtained according to the invention can be used in very many ways for determining the location. A few examples of the use of distance data for locating will be given in the following; however, the invention is not limited to these examples. The stored distance data S_i and the location data of the base stations may be outputted as a graphical printout, for example. Figure 3 shows an example of a graphical printout in a case where the distance has been defined by means of two base stations: the serving base station BTS1 and a neighbouring base station BTS2. Two circles with a different radius have been drawn round both base

stations such that the base stations are at the centre point of the respective circles. The remainder of the radii of the concentric circles corresponds to the uncertainty ΔS in the distance, caused by the resolution, e.g. 550 metres. The inner circle thus corresponds to the distance S_i calculated on the basis of the timing advance, whereas the outer circle corresponds to the calculated distance plus the resolution of the distance $S_1+\Delta S$. On the basis of merely the measurement made by the serving base station BTS1, for example, the MS may be located anywhere in the annular area defined by the BTS1-centred circles, i.e. inside the outer circle but outside the inner circle. By taking into account the measurement results of both base stations BTS1, BTS2, the location of the MS can be confined to the hatched area A in Figure 3, i.e. the intersection of the circles (step 24 of Figure 2). The analysis of the graphical printout and grounds for the above argumentation will be explained more closely below. If a suitable scale is selected for the graphical representation, the location determination printout can be appropriately placed on top of a map. An emergency service centre may be informed of the location of the MS by facsimile, for instance. A telefax containing a graphical or numeric printout may also be sent automatically to a predetermined facsimile number.

The accuracy of the locating of an MS improves when the number of neighbouring base stations participating in the measurement increases. The distances of the MS from the base stations BTSi also have an effect on the accuracy of the location determination. If the distance of the MS from each measuring base station is precisely the resolution of the distance, 550 m, midway between multiples n*550m+225m (n = 0, 1, 2...), the result is as

inaccurate as it can be. In this case, the location determination is confined to an area the radius of which is 225 m on the average. A corresponding situation arises if the mutual distance between base stations measuring in opposite directions is a multiple of the resolution ΔS of the distance. In other cases, measurements made from opposite directions specify the locating of the MS by excluding part of the location area defined by the other base stations. This exclusive inference is based on the propagation properties of a radio signal. Obstacles on the transmission path of a direct radio beam cause the radio beam to be reflected and thus delay the arrival of the transmission of the MS at the base station; therefore the distance between the MS and the BTS is in fact shorter than the distance calculated on the basis of the timing advance. On the other hand, the velocity of the radio signal is not faster than the velocity of light, wherefore the actual distance cannot be substantially longer than the distance theoretically calculated on the basis of the timing advance. The location of an MS can thus be defined in the most reliable manner if the minimum distance of the MS can be defined by exclusive inference.

The exclusive inference is illustrated in Figure 3. Figure 3 shows a combination of the annular areas of the serving base station BTS1 and a neighbouring base station BTS2, defined on the basis of timing advances TA_1 and TA_2. On the basis of only the measurement made by the BTS1, the MS could, because of reflections, be located even closer than at the distance of the shorter radius S_1 from the BTS1, but not farther than at the distance of the longer radius $S_1+\Delta S$. This also applies to the circles of the BTS2. When the results are combined, the location of the MS can be

confined to the overlapping area of BTS1 and BTS2, whereby the outer circles define the hatched area A in the figure as the location area of the MS, thus removing the inaccuracy caused by multipath propagation. As can be seen from Figure 3, even two suitably positioned base stations improve the locating of an MS essentially by excluding the areas in which the MS cannot be located.

The graphical printout of base station distances shown in Figure 4 illustrates the principle of keeping the outer circle of each base station as the outer boundary line. Figure 4 shows a combination of distance results of three base stations BTS1, BTS2, BTS3. The outer circles of BTS1, BTS2 and BTS3 define the location area A of the MS. The inner circle of the BTS2 does not represent an absolute minimum distance of the MS from the BTS2, wherefore it does not further confine the possible location area. In Figure 5, the BTS2 is more advantageously positioned, and the location area A of the MS can be confined to a relative small area, about 200*250 metres, with only three base stations. If there were a larger number of measuring base stations, the accuracy of the location determination would be further improved.

The drawings and the associated specification are intended merely to illustrate the inventive concept. In its details, the determination of the location of an MS may vary within the scope of the appended claims. Although the invention has been described above mainly with reference to the GSM system for mobile communications, the method can also be applied to some other digital TDMA system.

Claims

1. A method for determining the location of a mobile station (MS) in a digital time division mobile communication network, comprising the steps of

determining the timing of the transmission of the mobile station (MS) at a serving base station (BTS1) by means of a timing advance so that the transmission of the mobile station (MS) is received at the serving base station (BTS1) in a correct time slot,

converting said timing advance data into base station distances, and

measuring signals from neighbouring base stations at the mobile station (MS) and reporting the measurement results to the network,

c h a r a c t e r i z e d in that it comprises

measuring, at one or more neighbouring base stations (BTS2, BTS3), timing advances suitable for timing the transmission of the mobile station (MS),

adding an inaccuracy term to said base station distances, and

determining the location of the mobile station (MS) as the intersection (A) of the base station distances rectified with the inaccuracy term.

2. A method according to claim 1, c h a r a c t e r i z e d by measuring the suitable timing advance at each of said neighbouring base stations (BTS2, BTS3) in such a way that the transmission of the mobile station (MS) is received at said neighbouring base station (BTS2, BTS3) in a correct time slot.

3. A method according to claim 1 or 2, c h a r a c t e r i z e d by commanding a call to be switched to a neighbouring base station (BTS2, BTS3) for the time of the measurement of the timing advance.

4. A method according to claim 3, c h a r a c -

t e r i z e d by handing over the call back to the serving base station (BTS1), when the neighbouring base station (BTS2, BTS3) has completed the measurement of the suitable timing advance.

5. A method according to claim 1 or 2, c h a r a c t e r i z e d by paging the mobile station (MS) after a call has ended for measuring the timing advance at the neighbouring base stations (BTS2, BTS3) and releasing the connection before the mobile station alarms a user.

6. A method according to claim 5, c h a r - a c t e r i z e d by rejecting the access attempt of the mobile station (MS) at the base station (BTS1, BTS2, BTS3) where measurement of the timing advance has been completed.

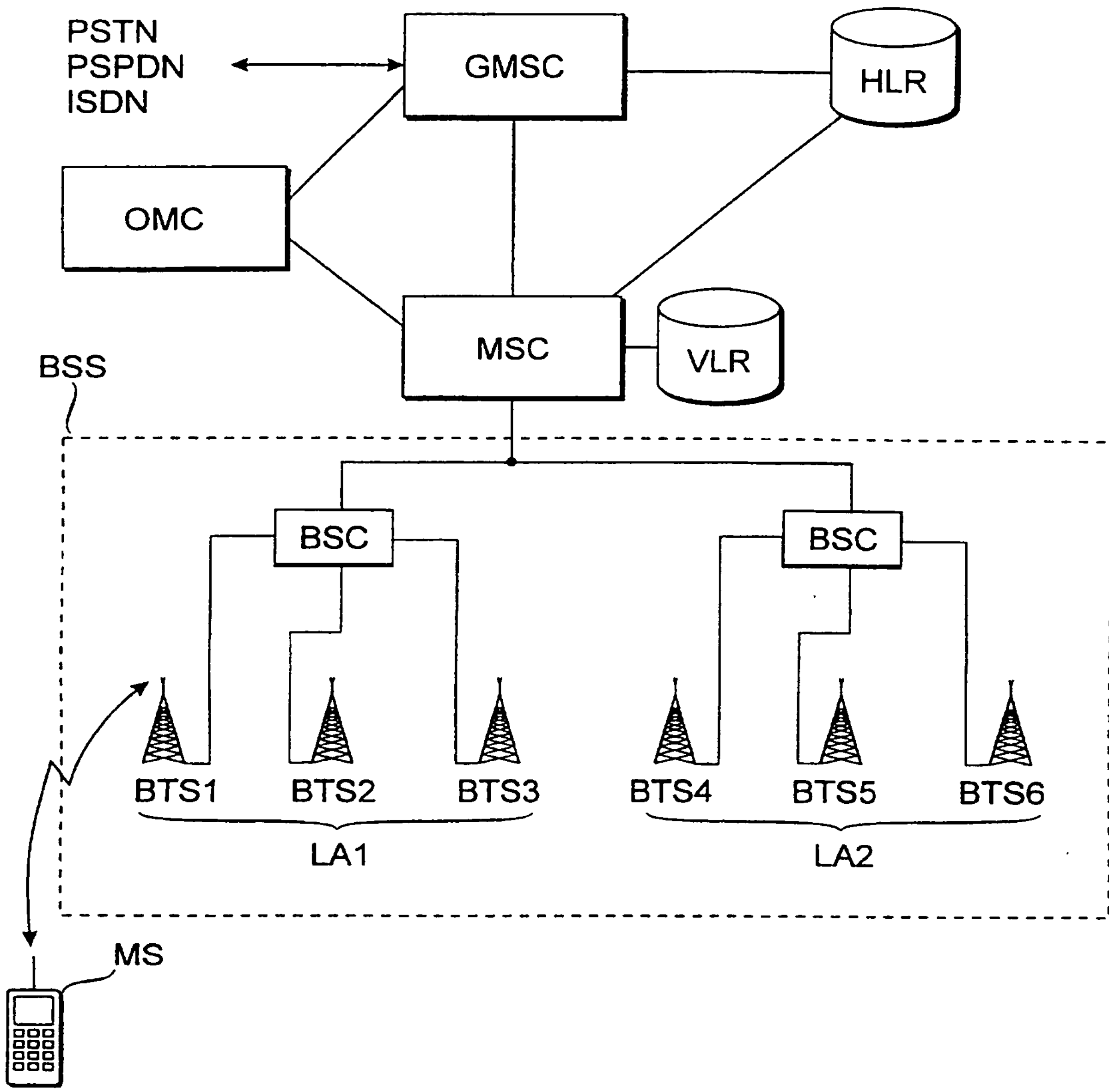
7. A method according to claim 5, c h a r - a c t e r i z e d by commanding the mobile station (MS) to monitor the broadcast frequency of the neighbouring base station (BTS2, BTS3) for the time the neighbouring base station (BTS2, BTS3) measures the timing advance.

8. A method according to any one of the preceding claims, c h a r a c t e r i z e d by defining the neighbouring base stations (BTS2, BTS3) participating in the measurement of the timing advance on the basis of the results of the base station signal measurements, reported by the mobile station (MS).

9. A method according to claim 1, c h a r a c - t e r i z e d by a further step of identifying the emergency call before triggering the timing advance measurements at the neighbouring base stations.

10. A method according to claim 9, c h a r - a c t e r i z e d by identifying the emergency call by comparing the directory number of the called party with predetermined emergency telephone numbers.

Fig. 1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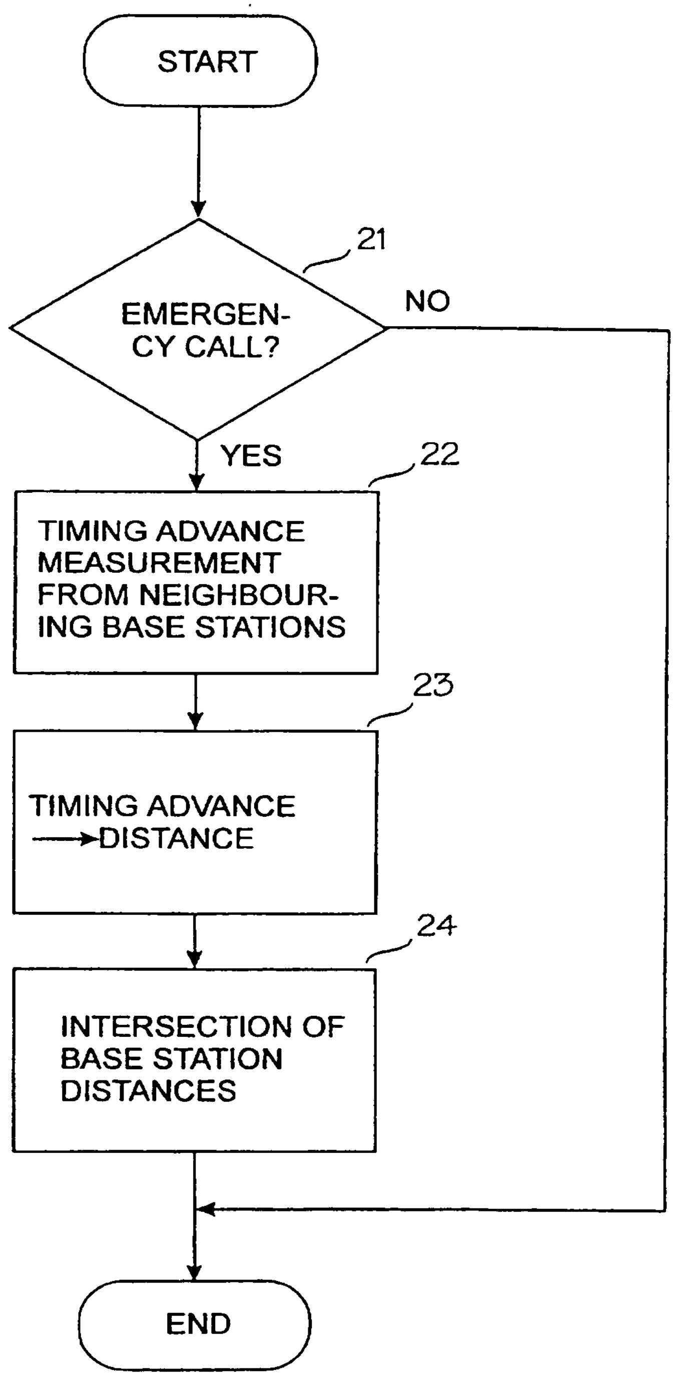
LA1
LA2
MS

Fig. 2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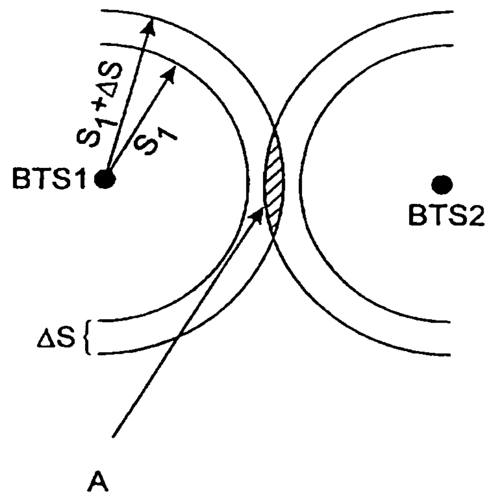

Fig. 3

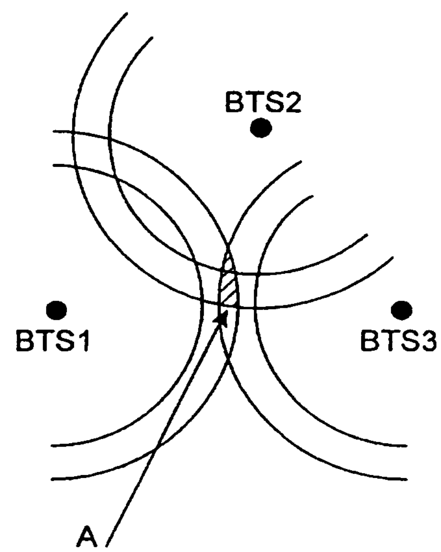

Fig. 4

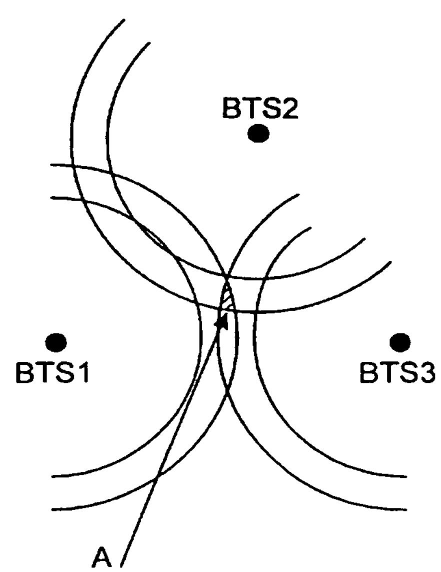

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 97/00035

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04Q 7/20, G01S 5/14
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9205672 A1 (TELEVERKET), 2 April 1992 (02.04.92), page 2, line 2 - line 9; page 4, line 19 - line 32; page 5, line 24 - line 38 --	1-10
X	EP 0320913 A2 (OY NOKIA AB), 21 June 1989 (21.06.89), column 1, line 44 - column 2, line 8, abstract --	1-10
X	EP 0631453 A2 (TELIA AB), 28 December 1994 (28.12.94), column 2, line 2 - line 9, abstract --	1-10

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 June 1997	11 -06- 1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Per Källquist Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 97/00035

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0335558 A2 (THE MARCONI COMPANY LIMITED), 4 October 1989 (04.10.89), column 2, line 13 - line 39, abstract --	1-10
A	EP 0679041 A2 (SIEMENS AKTIENGESELLSCHAFT), 25 October 1995 (25.10.95), abstract --	9-10
A	WO 9413113 A1 (NOKIA TELECOMMUNICATIONS OY), 9 June 1994 (09.06.94), page 6, line 27 - page 7, line 20, abstract --	7-8
A	EP 0431956 A2 (MOTOROLA, INC.), 12 June 1991 (12.06.91), column 4, line 19 - line 30 -- --------	1-10

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Information on patent family members

03/06/97

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